D4.2 Stability and change

Continuity and change—Ecosystems

Standard level and higher level: 4 hours

Additional higher level: 2 hours

Guiding questions

• What features of ecosystems allow stability over unlimited time periods?

• What changes caused by humans threaten the stability of ecosystems

SL and HL

D4.2.1—Stability as a property of natural ecosystems
Illustrate ecosystem stability with evidence of forest, desert or other ecosystems that have shown continuity over long periods. There is evidence for some ecosystems persisting for millions of years.

- **Ecosystem stability** is the maintenance of the overall structure and function of an ecosystem with time
  - Stability ensures **continuity through change**; even though its communities & abiotic factors may undergo some changes, its distinct characteristics remain (like productivity & food webs)
- Evidence shows that forest & desert ecosystems have shown continuity over long periods
  - Fossils indicate the presence of similar kinds of plants and animals for millions of years

D4.2.2—Requirements for stability in ecosystems
Include supply of energy, recycling of nutrients, genetic diversity and climatic variables remaining within tolerance levels.

- Requirements for stability in ecosystems:
  - **Supply of energy**: the sun provides a continuous supply of energy for ecosystems because energy is lost between trophic levels
  - **Recycling of nutrients**: since matter is finite, decomposition & nutrient cycles allow it to be reused by organisms
  - **Genetic diversity**: an ecosystem with populations that maintain high genetic diversity is resilient to ecosystem pressures
  - **Climatic variables**: precipitation, temperature, light intensity, etc. are abiotic factors that determine whether environmental conditions remain within tolerance levels
    - Stability is maintained only while environmental conditions remain within the limits that organisms can tolerate

D4.2.3—Deforestation of Amazon rainforest as an example of a possible tipping point in ecosystem stability

Include the need for a large area of rainforest for the generation of atmospheric water vapour by transpiration, with consequent cooling, air flows and rainfall. Include uncertainty over the minimum area of rainforest that is sufficient to maintain these processes.
Application of skills: Students should be able to calculate percentage change. In this case the extent of deforestation can be assessed by calculating the percentage change from the original area of forest.

- A **tipping point** is a critical threshold where further changes to an ecosystem variable cause abrupt, self-amplifying, and often irreversible shifts to a different ecosystem state
    - For example, a lake shifting from clear water (state 1) to turbid water (state 2) due to pollution
- **Deforestation of Amazon rainforest** is an example of a possible tipping point in ecosystem stability
    - Deforestation decreases plant transpiration, so less water enters the atmosphere
    - This reduces cloud formation & rainfall, which leads to drier & hotter weather with less air flow
    - Changes in these climatic variables can push vegetation beyond tolerance levels, causing instability
    - This is a **positive feedback cycle** because the initial change (loss of trees) is amplified
    - The tipping point is not yet known, which makes prevention efforts essential since the tipping point might not be recognized until it has already been crossed
        - Measuring extent of deforestation as part of prevention efforts can be done by calculating percentage change from the original (old) area of the Amazon forest

$$\textbf{Percentage change} = \frac{\text{Current Forest Area - Old Forest Area}}{\text{Old Forest Area}} \times 100$$

D4.2.4—Use of a model to investigate the effect of variables on ecosystem stability

Mesocosms can be set up in open tanks but sealed glass vessels are preferable because entry and exit of matter can be prevented but energy transfer is still possible. Aquatic or microbial ecosystems are likely to be more successful than terrestrial ones.

- **Mesocosms** are controlled models of an ecosystem used to study ecological processes
    - **Open mesocosms** (e.g. tanks open to the air) allow matter & energy transfer
    - **Closed mesocosms** (e.g. sealed glass vessels) allow energy transfer (but not matter)
        - They are preferable because they allow for greater experimental control over variables
- **Aquatic** or **microbial mesocosms** are likely to be more successful than terrestrial ones:
    - Nutrients can circulate through aquatic mesocosms faster
    - Microbial mesocosms require less space & resources to maintain than terrestrial ones

NOS: Care and maintenance of the mesocosms should follow IB experimental guidelines.

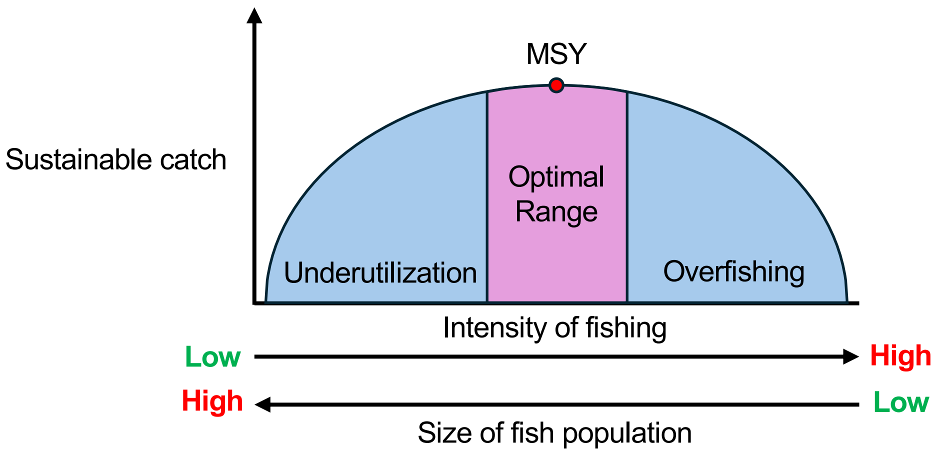
- Care and maintenance of the mesocosms should follow IB experimental guidelines; ethical treatment of organisms must be clearly described to minimize suffering of organisms.

D4.2.5—Role of keystone species in the stability of ecosystems
Students should appreciate the disproportionate impact on community structure of keystone species and the risk of ecosystem collapse if they are removed.

- Ecosystem stability depends on the roles and interactions of particular species
- A **keystone species** has a disproportionately large effect on the structure of its ecosystem relative to its abundance
- Loss of keystone species can lead to ecosystem collapse due to trophic cascades

D4.2.6—Assessing sustainability of resource harvesting from natural ecosystems
Sustainability depends on the rate of harvesting being lower than the rate of replacement. Include one terrestrial plant species and one species of marine fish as examples of renewable resources and how sustainability of harvesting can be assessed.

- The sustainability of harvesting organisms from natural ecosystems needs to be assessed in order to maintain ecological stability
- Sustainable harvest of organisms depends on **harvesting rate** being lower than **replacement rate**
  - Replacement rate is the rate at which a harvested population replaces the individuals removed
  - Replacement rate is highest when half of the population is harvested, because population growth is highest at half the carrying capacity (0.5*K*)
  - **Maximum sustainable yield (MSY)** is achieved when half the population of a renewable living resource is harvested, but it does not account for the effects of seasonal variation, weather, etc. on the harvested population
- In reality, there is constant financial pressure to harvest beyond the MSY, which threatens species
  - **Overfishing of Atlantic cod** has led to global population collapse in the 1990s, but sustainability efforts (like stringent fishing regulations) are allowing its populations to recover
    - Sustainable fishing effort involves imposing quotas for each boat & not harvesting during breeding season
  - **Logging of Brazilian nut trees** (a source of timber) in the Amazon rainforest is regulated because they are keystone species that are difficult to cultivate in farms
    - Sustainable timber harvest involves using timber from fallen trees & leaving enough trees for effective seed dispersal & germination



D4.2.7—Factors affecting the sustainability of agriculture

Include the need to consider soil erosion, leaching of nutrients, supply of fertilizers and other inputs, pollution due to agrochemicals, and carbon footprint.

- Sustainable agriculture ensures that food production does not destroy the ecosystem it depends on
- Factors affecting the sustainability of agriculture (**NPC ScreenShots**):
  - **Nutrient leaching**: is the downward movement of soil minerals & nutrients due to irrigation
    - Nutrients could move from farmland & become pollutants in other ecosystems
  - **Pollution due to agrochemicals**: agrochemicals are chemicals used in agriculture to increase crop production (e.g. fertilizers, insecticides, herbicides)
    - These chemicals can harm non-target species like pollinators & bioaccumulate/biomagnify
  - **Carbon footprint**: is the amount of greenhouse gases released by agricultural activities, like manufacturing of agrochemicals, clearing of forests for farmland, & methane emissions by livestock
    - Greenhouse gases cause climate change, which may push climatic variables beyond tolerance levels
  - **Soil erosion**: is the removal of the nutrient-rich upper soil layer (**topsoil**) by natural or human activities
    - Repeated ploughing or overgrazing from livestock lead to soil erosion, which forces farmers to use more agrochemicals (thus causing more pollution)
  - **Supply of fertilizers & other inputs**: an agricultural system that relies on a high supply of fertilizers & other farming inputs depends on production processes that cause pollution

D4.2.8—Eutrophication of aquatic and marine ecosystems due to leaching

Students should understand the effects of eutrophication resulting from leaching of nitrogen and phosphate fertilizers, including increased biochemical oxygen demand (BOD).

- **Eutrophication** is the increased availability of nutrients in bodies of water due to leaching of nitrogen & phosphate fertilizers or sewage outflow
  - Initially, it leads to **algal blooms** (exponential growth of algal populations), which prevents sunlight from reaching other aquatic organisms beneath the thick algal film
  - When large algal populations eventually die, **high decomposition rates** decrease oxygen levels beyond tolerance levels, leading to **ecosystem death**
- The **biochemical oxygen demand (BOD)** is the amount of dissolved oxygen used by microorganisms during decomposition
  - BOD is a good measure of eutrophication because leaching increase the amount of organic matter available for decomposers, which raises BOD & lowers oxygen levels available for higher animals

D4.2.9—Biomagnification of pollutants in natural ecosystems

Students should understand how increased levels of toxins accumulate in the tissues of consumers in higher trophic levels. Include DDT and mercury as examples.

- **Bioaccumulation** is the gradual buildup of substances (e.g. toxins) within an individual organism
  - It occurs when a substance is absorbed faster than it is eliminated
  - Fat soluble substances are more likely to bioaccumulate because they are harder to eliminate
- **Biomagnification** is the increase in toxin concentration at successively higher trophic levels
  - Apex predators are exposed to the highest toxin concentration because they consume all the toxins contained in their prey
- For example:
  - Mercury bioaccumulates in body tissues as **methyl mercury** (a lipid-soluble substance), leading to biomagnification & mercury poisoning in humans who consume fish with high mercury levels
  - **DDT** is an insecticide that increases in concentration throughout aquatic & terrestrial food chains
    - Biomagnification of DDT levels caused the eggshells of predatory birds to thin, which lowered reproductive success & population size

D4.2.10—Effects of microplastic and macroplastic pollution of the oceans

Students should understand that plastics are persistent in the natural environment due to non-biodegradability. Include examples of the effects of plastic pollution on marine life.

- **Plastics** are persistent in the natural environment because they are **non-biodegradable**
  - With time, plastics may break down into smaller pieces but that does not make them less harmless
    - **Macroplastics** are plastic items larger than 5mm
    - **Microplastics** are plastic items smaller than 5mm
- Macroplastic pollution causes injury to marine life through entanglement or ingestion
- Microplastic pollution can lead to cellular stress, disruptions in body processes, & higher risks of cancer

NOS: Scientists can influence the actions of citizens if they provide clear information about their research findings. Popular media coverage of the effects of plastic pollution on marine life changed public perception globally, which has driven measures to address this problem.

- Popular media coverage of the effects of plastic pollution on marine life changed public perception globally, which has driven measures to address this problem
  - This was enabled by the ability of scientists to clearly communicate their research findings

D4.2.11—Restoration of natural processes in ecosystems by rewilding
Methods should include reintroduction of apex predators and other keystone species, re-establishment of connectivity of habitats over large areas, and minimization of human impact including by ecological management. Include the example of Hinewai Reserve in New Zealand.

- **Rewilding** aims to restore the natural processes in damaged ecosystems by:
  - **Reintroduction of keystone species** like apex predators or pollinators
  - **Reestablishment of habitat connectivity** to reduce ecosystem fragmentation
  - **Minimization of human impact**, including by ecological management (e.g. reducing logging)
- Rewilding of the Hinewai Reserve in New Zealand was done by removing invasive alien species in order to reestablish what was once used as farmland into native forest

Additional higher level

D4.2.12—Ecological succession and its causes
Succession can be triggered by changes in both an abiotic environment and in biotic factors.

- **Ecological succession** is a change in the structure of an ecological community over time
  - Succession can be primary, secondary, or cyclical
- Succession can be triggered by changes in both abiotic and biotic factors
  - Abiotic factors include volcanic eruptions, glacier retreats, storms, fires
  - Biotic factors include colonization by new species, disease, predation, competition
  - Both factors can influence each other in different ways to trigger succession
- The **final stage of succession** involves the establishment of a climax community
  - A **climax community** is the stable community that characterizes the ecosystem produced by succession under a particular set of environmental conditions

D4.2.13—Changes occurring during primary succession
Use any suitable terrestrial example to illustrate these general principles: increases in size of plants, amount of primary production, species diversity, complexity of food webs and amount of nutrient cycling.

- **Primary succession** occurs when an ecological community is established on an area with little or no biotic factors present (e.g. volcanic rocks with no vegetation)
  - **Pioneer species** (the first organisms to colonize the area, usually moss or lichen) invade the new land to establish soil capable of sustaining plant growth
  - Small plants will then grow & die; their decomposition will cause further changes to the soil to allow nutrient cycling & sustainment of larger plants
  - Higher primary production enables the establishment of more complex food webs with increasing species diversity, eventually resulting in a climax community
- **Secondary succession** occurs when an ecological community is established after a disturbance removes a pre-existing community, leaving remnants of a previous ecosystem
  - It is faster than primary succession & occurs more commonly (thus is better studied)

D4.2.14—Cyclical succession in ecosystems
Students should appreciate that in some ecosystems there is a cycle of communities rather than a single unchanging climax community. Students should refer to an example.

- **Cyclical succession** occurs when an ecosystem repeatedly cycles through different communities instead of remaining in a stable climax community
    - The change could be driven by disturbances or by species themselves
- For example, **California chaparral** contain shrubs & evergreen trees that experience repeated wildfires, so they repeatedly reestablish themselves until another periodic fire restarts the cyclical succession

D4.2.15—Climax communities and arrested succession
Given any specific environmental conditions, ecological succession tends to lead to a particular type of climax community, but human influences can prevent this from developing. Use grazing by farm livestock and drainage of wetlands as examples.

- **Arrested succession** occurs when disturbances prevent the natural development of an ecosystem towards its climax community
    - When succession is arrested, an ecosystem is maintained at an early or intermediate stage
- Human activities can cause arrested succession, for example:
    - **Grazing of farm livestock** removes tree seedlings, maintaining grassland where forests would otherwise develop
    - **Drainage of wetlands** leads to drier soils which negatively affects wetland species
        - The development of a wetland ecosystem is thus arrested & succession may be diverted to other types of ecosystems
- Reducing the disturbance may allow succession to resume, but recovery may be slow

Linking questions

• What is the distinction between artificial and natural processes?

• Over what timescales do things change in different biological systems?

Review questions

SL and HL

- Define ecosystem stability. [1]
- Define ecological tipping point. [1]
- Define biochemical oxygen demand (BOD). [1]
- State **two** requirements of ecosystem stability. [2]
- Outline the role of keystone species in ecosystem stability. [2]
- Explain why the maintenance of climatic variables at tolerance levels is important for ecosystem stability. [3]
- Explain why genetic diversity is an important requirement of ecosystem stability. [3]
- Outline how rewilding can restore natural processes in ecosystems. [3]
- Explain why deforestation of Amazon rainforest is a potential tipping point. [3]
- Explain how leaching of nutrients leads to eutrophication. [3]
- Outline the requirements of ecosystem stability. [4]
- Discuss the role of sustainable harvesting in maintaining ecological stability. [7]
- Describe how persistent pollution affects the stability of ecosystems. [7]

Additional Higher Level

- Define a climax community. [1]
- Outline **two** human influences that can prevent the establishment of a climax community. [2]
- Outline how primary succession occurs. [4]
- Using examples, distinguish between primary, secondary, and cyclical succession. [6]
- Explain how natural ecosystems can remain stable over long periods of time despite undergoing continuous change. [7]

References

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